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13. ABSTRACT (Maximum 200 words) A full wave spectral domain method of moments code was developed and optimized for the analysis of microstrip discontinuities in open and shielded MIC environments. This code was used as a benchmark for the newly developed spatial decomposition technique (or SDT) based solver. The initial results of SDT-based solver indicate that it needs to be further optimized, especially for electrically small structures in order to be faster than the optimized SDM-MoM solver. However, for electrically large discontinuities even the un-optimized SDT-based approach appears to be faster than the optimized version of the SDM-MoM solver.			
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LIST OF MANUSCRIPTS

R. T. Anderson and B. Beker, "Computational considerations for accurate solution of general open microstrip discontinuity problems," *1999 Int. AP/URSI Symp. Digest*, Orlando, FL, July 1999.

B. Beker, "Theoretical aspects of formulating multi-conductor microstrip line problems in shielded structures with anisotropic substrates," *1999 Int. AP/URSI Symp. Digest*, Orlando, FL, July 1999.

B. Beker, Y. Chen and J. Cain, "Modeling of material anisotropy in microwave and millimeter-wave guided wave structures," **Invited chapter** in *Recent Research in Developments in Microwave Theory and Techniques*, Trans-world Research Network, 1999.

B. Beker, "Dispersion characteristics and packaging effects of asymmetric multi-conductor transmission lines printed on anisotropic substrates," submitted to *IEEE Trans. Microwave Theory and Techniques*.

SCIENTIFIC PERSONNEL

One graduate students and the PI were supported during this reporting period. Ronald Anderson (Ph.D. graduate student) supported 1-1-99 to 12-31-99 and Benjamin Beker (PI) was supported 7-1-99 to 12-31-99.

Report of INVENTIONS

None during this reporting period

SCIENTIFIC PROGRESS AND ACCOMPLISHMENTS

The research effort during this reporting period focused on completing and optimizing the 2-D and 3-D spectral domain method of moments based algorithms, implementation of the spatial decomposition technique for microstrip discontinuities, and investigation of anistoropic material effects on the impedance characteristics of multi-conductor transmission lines. Research results were summarized in two papers and presented in two conference papers.

Specific aspects of the research included assessment of using the non-uniform piecewise linear (or sub-domain) basis functions in the spectral domain technique in favor of the entire domain basis functions for current expansion. This approach proved to be beneficial in investigating packaging effects on the propagation and impedance characteristics of multi-conductor transmission lines printed on anisotropic substrates. In addition, the sub-domain basis functions appeared to perform better than the entire domain functions in accurately extracting the current distribution, especially when microstrip transmission lines were located close to the side walls of the package.

Furthermore, the sub-domain basis function formulation allowed for conveniently applying matrix algebra formalism to calculate the modal characteristic line impedance matrices for multi-conductor transmission lines. The matrix approach was especially helpful to simplify the computation of such quantities for transmission lines printed on anisotropic substrate. The reason for this is that for waves in planar anisotropic

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media, the field components are coupled far more intimately than in isotropic media. The use of matrix algebra permits for treating such tight coupling in a systematic and straightforward manner. The results of this research are in the process of being prepared for publication.

For 3-D structures (open and shielded), the MoM in the spectral domain was implemented and further optimized. The optimizations included a novel integration technique around the highly singular poles of the Green's function as well as the implementation of the Shank's transforms for evaluating the "tail" (spectral contribution from past the poles to infinity) integrals associated with open structures. The use Shank's transform is also presently being investigated for potential use to accelerate the summations associated with the discrete spectral variable along the side walls of shielded structures. These optimizations have resulted in a 3-D spectral domain method of moments code that was used as a benchmark for the spatial decomposition technique (SDT) based solution to microstrip discontinuity problems.

The first version of the SDT-based code was also developed during this reporting period. The initial results of its performance were compared to those of the optimized SDA-MoM approach. The preliminary data show that there is a need for further optimization of the SDT-based discontinuity code, especially for smaller structures. However, it appears that even the un-optimized SDT solver performs better than the optimized SDM-MoM solver for very large structures.

There are several goals set for the next reporting period, which will be the last year of this grant. Primarily, the newly developed SDT-based discontinuity analysis approach will have to be optimized. There are several numerical techniques that are presently in use that will be improved. In addition, there are two theoretical areas that will be addressed as well. One deals with the way the spatial domains into which the overall structure is subdivided are selected. The second involves reassessing the manner in which iterative process ("marching" or "sweeping" over the domains) is applied. It is expected that some reordering of operations and some reformulation of the problem will speed up the convergence of the numerical solution.

TECHNOLOGY TRANSFER

Interaction is continuing with the technical personnel at DoD labs and private industry. Specifically, technical contacts with the Army Research Lab and the Army Space Missile Defense Command lead to discussions and submission of white papers seeking further funding for the practical extension of this basic research work. In addition, an interest in this and related work has resulted in funding from the ONR to apply the results of the basic research to passive electronic components in low noise amplifier circuit oscillators used wireless systems. Further parallel efforts are also underway to expand the applications of this research to tunable passive higher frequency microwave components and to cultivate the interest of NASA and the NRL.

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There are three papers in preparation which will be submitted to the IEEE Transactions on Microwave Theory and Techniques next reporting period. Most of the research effort is being carried out by beginning Ph.D. graduate students. They are beginning to mature as scholars and are expected to start reporting their findings in technical journals.

SCIENTIFIC PERSONNEL

Dr. Alexander Kasyanov (visiting scholar) supported 3-15-97 to 5-15-97, Dmitri Garmatiuk (Ph.D. graduate student) supported 2-15-97 to 12-31-97, and Ronald Anderson (Ph.D. graduate student) supported 8-15-97 to 12-31-97.

Report of INVENTIONS

None during this reporting period

SCIENTIFIC PROGRESS AND ACCOMPLISHMENTS

The research effort during this reporting period was primarily focussed on issues associated with the numerical implementation of the spatial decomposition technique (SDT). Several important aspects of the numerical formulation were addressed, starting with the re-formulation of the spectral-domain Green's function representing sources in planar anisotropic media. It was discovered during this research that careful re-normalization of the spectral variables (Fourier transforms of the spatial variables) was required to obtain stable numerical solutions for the propagation constants, even in uniform MIC structures. The presence of the off-diagonal elements of the permittivity and/or permeability tensors, gives rise to fourth order powers of the free-space wavelength λ_0 (in contrast to the second order powers in isotropic medium) in the Green's function and characteristic equation for the propagation constants in the anisotropic medium. This is due to the fact that anisotropic medium can support twice the number of guided wave modes compared to its isotropic counterpart. As a result, at higher frequencies, the 4th order powers of λ_0 lead to evaluation of quantities with very large numbers in the Green's function and in the solution of the characteristic equation for the propagation constants. This causes numerical problems and unnecessarily prolonged root searching, even when using double precision. It was found that this numerical problem can be easily circumvented by properly normalizing the spectral variables with respect to the free-space propagation constants. Although this procedure is tedious analytically, it leads to exceptionally stable numerical implementation and significantly faster root searching.

In addition, as part of the above effort, it was found that the characteristic equation (namely, the determinant of the Green's function) of many guiding MIC-type structures on grounded substrates (isotropic and anisotropic), has a very common behavior. This behavior can be expressed in terms of frequency and medium parameters approximately using rather simple curve fitting schemes. The resulting approximate

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representation of the characteristic equation proved to be very useful in accurately estimating the initial guess for the propagation constants of uniform lines connected to MICs discontinuities.

Other aspects of the numerical formulation for the spectral-domain method of moments (MoM) type techniques were investigated as well. Novel optimization schemes for generating MoM system matrices were conceived. They were intended to speed up the filling of large system matrices, which involve lengthy summations over the index of the transverse spatial transform for shielded structures and an integration variable for open structures.

The efforts described above served as the starting point for the development of the new SDT algorithms. It was important to make all possible improvements to the non-SDT parts of the integral equation solving algorithms prior to attempting to implement and optimize the SDT implementation itself. Following this, the first version of the SDT algorithm was written and tested for the microstrip step discontinuity. The initial results are very encouraging, showing the potential for accelerating the conventional spectral domain MoM techniques by, at least, an order of magnitude.

Next year, SDT will be applied to the analysis of more general MIC discontinuities, including microstrip filters. In addition, complex image theory will be employed as well, to find accurate closed form approximations to the Green's functions over appropriate ranges of the spectral variable. They are expected to yield further speed-up of SDT based algorithms used in the numerical analysis of electrically large MIC structures containing discontinuities.

TECHNOLOGY TRANSFER

New contacts were established with the technical staff of the Wireless Communications division of National Semiconductor Corporation. They are interested to find out if this research can be applied to the prototyping of embedded discrete passive components such as capacitors and inductors in low temperature co-fired ceramic (LTCC) substrates to design bandpass filters. In addition, technical exchange is continuing with AVX Corporation who have agreed to provide samples of bandpass filters for conducting measurements to validate the theoretical and numerical work presently underway at USC.

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None during this reporting period

SCIENTIFIC PERSONNEL

Alexander Kasyanov and Dmitri Gramatiuk were selected from the nationally conducted search. They will be supported starting next reporting period.

Report of INVENTIONS

None during this reporting period

SCIENTIFIC PROGRESS AND ACCOMPLISHMENTS

The initial four months of the project focused on laying the technical foundation for the spatial decomposition technique (SDT) and complex image theory in anisotropic media. Several variations of the spatial decomposition technique were selected for evaluation to determine the advantages and disadvantages of the analytical formulation versus numerical implementation and efficiency. A microstrip step discontinuity was chosen to be the first demonstration problem for the application of the SDT, since it is the basic building block in many MIC's.

Modifications to the existing complex image theory were made to account for the anisotropic properties of microwave and millimeter wave IC substrates. Initial analytical formulations to the MIC boundary value problems were started, and several numerical approaches were considered for their implementation. The first Green's function to which complex image theory will be applied consists of a point source located at the interface between air and grounded anisotropic substrate. The reason for choosing this geometry is that it can be easily extended to other more general and practical planar filter problems.

TECHNOLOGY TRANSFER

Technical contacts with appropriate personnel at the Army Research Lab were established for advice and evaluation of the relevance of the proposed research in DoD applications. Additional technical contacts were formed with the AVX Corporation, a major US supplier of passive electronic components, to assess the value of this research in development of improved frequency agile planar microstrip filters in commercial wireless applications.